GeoLidarObservatory: Atmospheric Observations using lidars in geosynchronous orbit

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Abstract

Active optical remote sensing from space will begin with altimetry (GLASS for example) and will follow with missions to observe tropospheric and stratospheric winds, as well as to measure vertical profiles of atmospheric water vapor, ozone and other gases. Range squared signal losses dominate the choice of altitude of the satellite and thus the near term missions will be in low earth orbit (LEO). However, one can still envision lidars located in geosynchronous orbit, 100 times more distant, if large mirrors, multi-kilowatt power supplies and pointing control to the micro-radian level become reality. ESTO has funded a concept study to evaluate the potential utility of lidar observations from geosynchronous earth orbit (GEO). One of the candidates for this study has been the Doppler wind lidar using the direct detection approach. This presentation will review the issues and illustrate the science and operational value of such observations.

Introduction

The primary advantage of a geosynchronous perspective on the atmosphere is the high temporal resolution compared to that obtained from a small number of satellites in LEO. Global coverage from GEO can be achieved with 5-6 platforms. Achieving direct, range resolved observations of winds and moisture will revolutionize our ability to monitor and predict severe atmospheric events on a routine basis. Significant improvements would be expected in forecasting: tropical cyclone tracks and intensity; tornado, hail and flooding; high winds including jet stream location/strength; and severe event precursors such as moisture convergence, tropospheric/stratospheric interactions, shear, etc..

Using passive remote sensing, we currently observe temperature, moisture and clouds from satellites in geosynchronous orbit. In some cases, winds can be derived from the apparent motion of the clouds and moisture structures. Vertical resolution, vertical coverage, height determination and accuracy remain key challenges to the usefulness of these observations in today's numerical models. However, given the range to target (~40000 km), the passive sensing approach has been the only practical means of obtaining observations with the temporal and global coverage afforded from that position.

Without regard to the technical challenges, active remote sensing from geosynchronous orbit is very attractive. In particular, the resolution and accuracy offered by active optical remote sensing would represent a quantum leap in the initialization of numerical models. The ESTO of NASA has funded an evaluation of the idea of lasers in geosynchronous orbit and the potential data products that would be achieved. Here, a notional concept for a GeoLidarObservatory (GLO) is briefly described and some aspects of the data products discussed.

Notional concept

One initial vision for GLO includes two lidars, one for measuring winds and the other for measuring water vapor. The general goals were:

- Parameters:
    - Tropospheric and stratospheric winds
    - Tropospheric moisture
- Space scales and accuracy:
    - < 20 km resolution
    - RMSE < 1 m/s
- Temporal resolution:
    - < 1 hour

To meet these goals, a number of technology issues must be addressed:

- Lidars beyond current state-of-the-art
    - very large optics (order 100 meters)
    - large laser transmitters
- Platform power supplies of the 5-10KW class
- Pointing knowledge and control requirements are stringent
- On-board processing to process lidar signals and adaptively target observations
- Downlink bandwidths adequate to deliver data in real-time to many users
- Rapid cycling of data through model assimilation routines at high spatial resolution (HPCs)
- Rapid dissemination of information (e.g. analyses and predictions)

Both the wind and water vapor sensors were examined in the ESTO study. However, here we report on just the wind lidar portion. Below are the general specifications for the DWL:

Doppler Wind Lidar (DWL)

- Laser transmitter
    - 1.5 joule at 355 nm (~ 4 J at 1060 nm)
    - 100 hz
- Telescope: 100 meter diameter
- Direct detection with SOTA system efficiencies
- Integration time: 5 seconds (720 obs/hour)
- Data product: LOSP wind speed with 1 km vertical resolution and <1 m/s RMS

Assessment of potential data products

A practical approach to using active remote sensing from GEO would involve two modes of observation: surveillance and targeted. These two modes are defined for this study to be:

- •Full disc
  - •Spatial resolution (clouds permitting)
    - •data point spacing: 200 km (~3860 points)
  - •Temporal resolution
    - •~ 5 second dwell with 6 hour revisit
- •Regional (7500 x 7500 km)
  - •Spatial resolution (clouds permitting)
    - •data point spacing: 200 km (~1400 points)
  - •Temporal resolution
  - •~ 5 second dwell with 2 hour revisit
  - •

Figure 1 illustrates the general sampling pattern for these two modes assuming off nadir scanning for wind retrievals.

Some general constraints on making observations within these targets are:

- •~1.5x108 km2 = area of Earth's surface viewable (full disc) between nadir angles of 3 (70) and 8.5 (12) degrees (angles in () are LOS relative to horizon)
- •~3860 cells (200 x 200 km)
- •Range to target is between 36,000 and 41,000 km
- •100 µrad pointing error can lead to > 4 km position errors

One of the primary issues in developing a notional DWL concept is the choice of nadir scan angle. In actuality, a range of nadir angles is needed to obtain the coverage illustrated in Figure 1. In Table 1, the trades in coverage and accuracy as a function of nadir angle are shown. The instrument parameters are those noted above, as well as assumed system efficiencies based upon current lidar capabilities. The accuracies above the 3km level are significantly better than those from rawindsondes. Those below the 3km level are slightly less accurate due to atmospheric attenuation, which is strongest near the surface.

Table 1
Distribution of data products and their accuracy as a function of nadir angle

Nadir Angle	% of total area viewed	Vel accuracy above 3 km	Vel accuracy below 3 km
3	6.2	.84	3.88
4	8.8	.64	2.94
5	12.2	.52	2.40
6	17.4	.45	2.06
7	28.3	.41	1.89
8	27.1	.46	2.14

8.5		.99	4.59

Summary

The idea of lidar observations from GEO has been considered and some “tall poles” identified. Accepting the basic assumption that 100 meter optics is possible, it is plausible that laser transmitters could be reasonably scaled from the current state of the art. The data products would have temporal and spatial resolution that would revolutionize atmospheric analysis and forecasting. The weakness of the wind data product from one platform is the lack of two wind perspectives to go along with the high resolution. Pairs of platforms with overlapping coverage would remove this weakness. Two platforms would also be of value to other remote sensing efforts, for example stereographic imagery.

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Figure 1
Simulated distribution of Doppler lidar wind observations from GLO